

Rockwell
Science Center

Analog Optical Signal Processing (AOSP)

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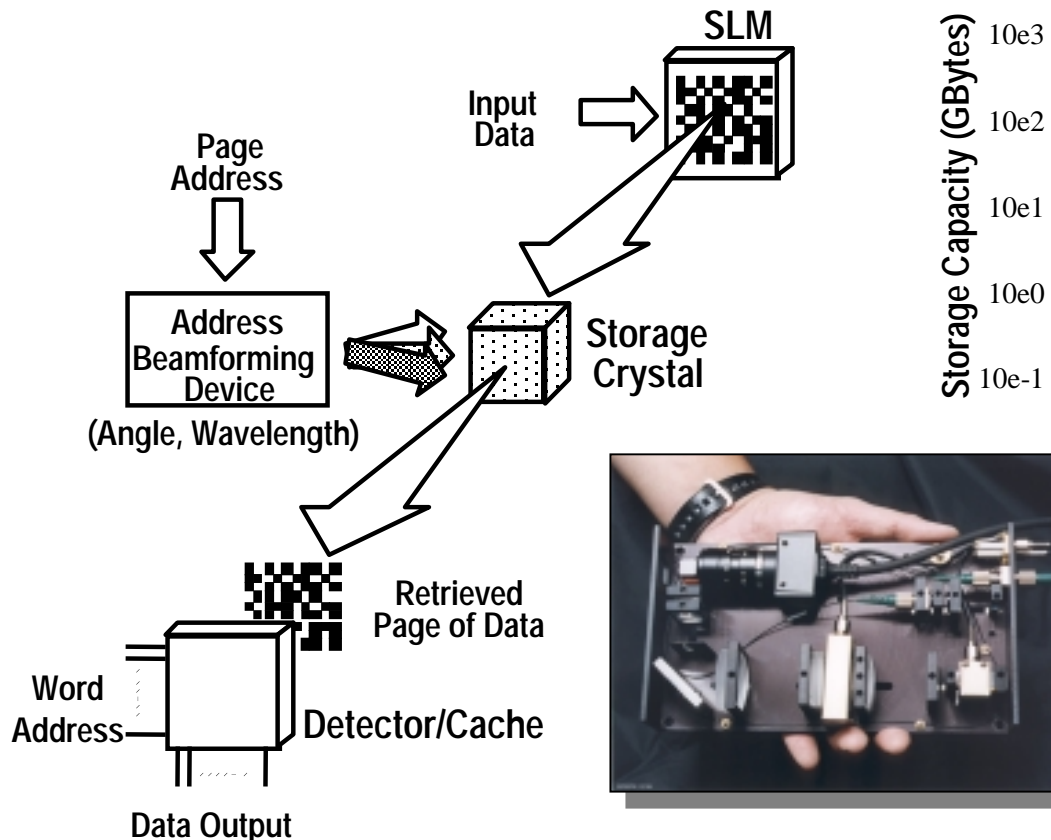
06 Dec 2000

Outline

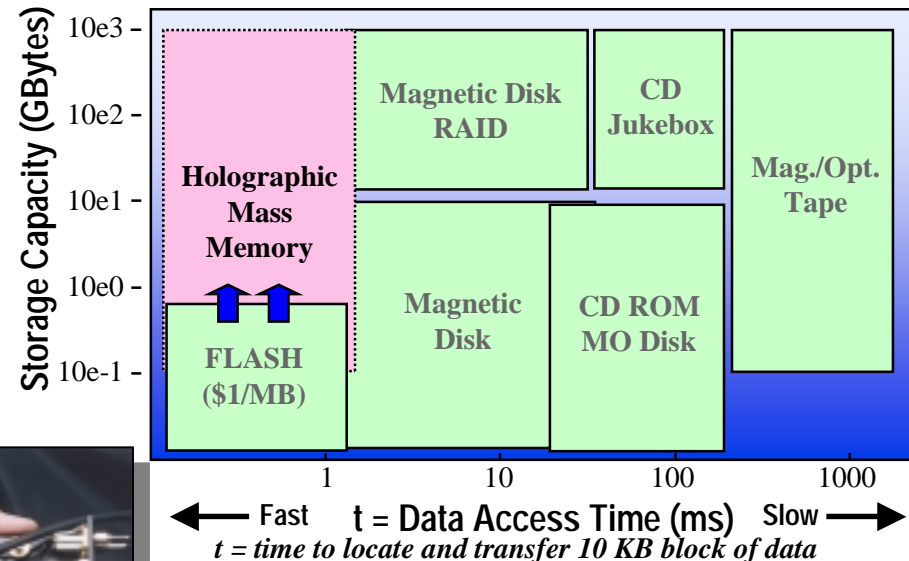
Chart 2

- Two analog optical signal processing examples
 - Optical Holographic Correlator (OHC)
 - Nonlinear Adaptive Interference Cancellation (NAIL)
- Interesting ASOP applications
- Concluding comments

Holographic Data Storage System



RGB images digitally stored and retrieved from memory



- Capacity: 5GB (analog) 100MB (digital)
- Random Access Time: 50 μs

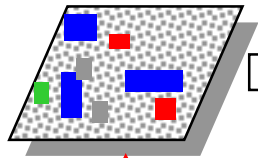
*Extensive experience
gathered from DARPA
HDSS program*



Automatic Target Recognition (ATR)

Chart 4

COMPLEX SCENE INPUT
(SAR, FLIR, Acoustic, ...)



Clutter
Reject



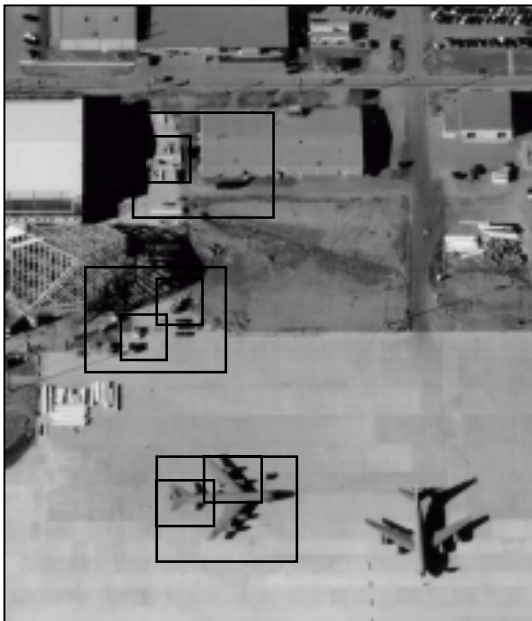
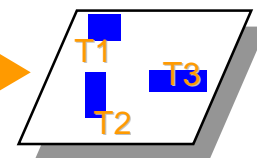
Potential
Targets



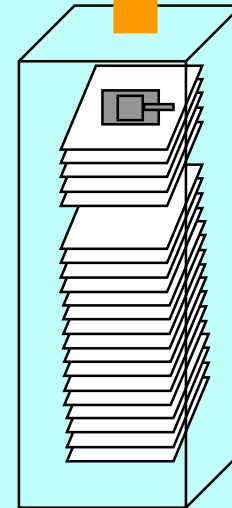
Classifier



TARGETS
IDENTIFIED



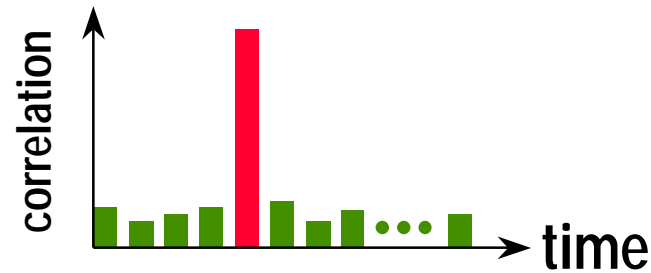
- Classifier must compare each potential target against entire reference database
- Computation/memory access intensive
- Electronic methods are slow due to use of sequential memory access / correlation



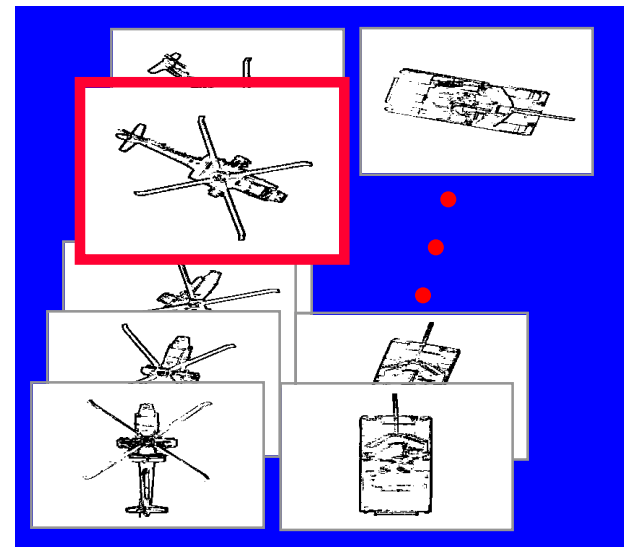
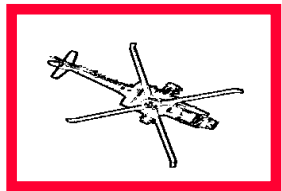
Large
Reference
Template
Library
(T1, T2, T3, T4, ..)

Correlation by Computer is a Serial Process

Chart 5



Rapid means of correlating images with a large template library are required



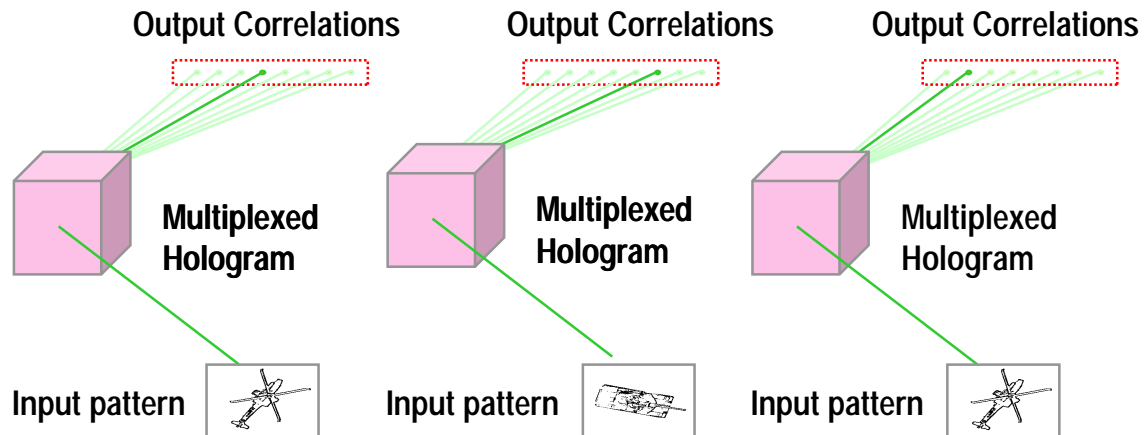
Potential Target

Computing Engine

Reference Database

Optical Holographic Correlator for ATR

Chart 6



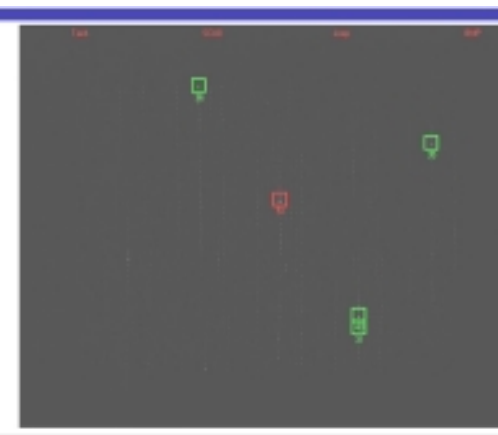
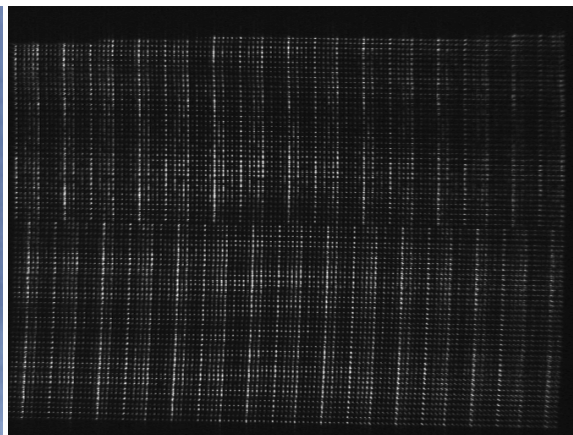
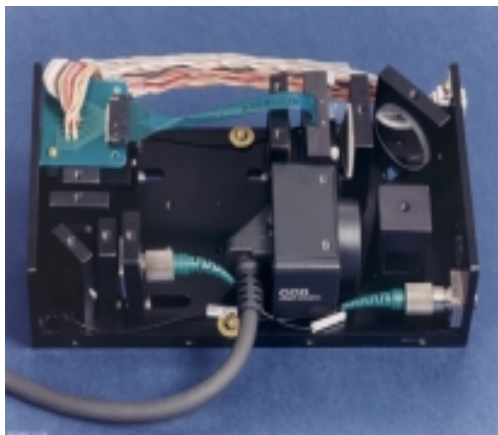
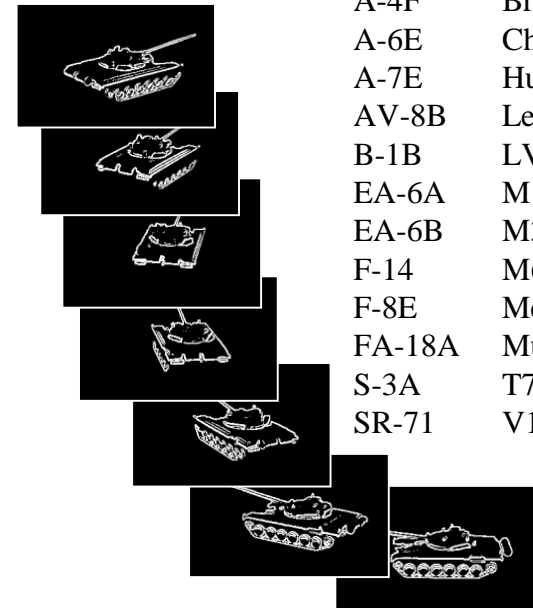
Parallel memory access / correlation operation allows huge increase in performance relative to sequential electronic signal processing

Aircraft

A-4F
A-6E
A-7E
AV-8B
B-1B
EA-6A
EA-6B
F-14
F-8E
FA-18A
S-3A
SR-71

Armor

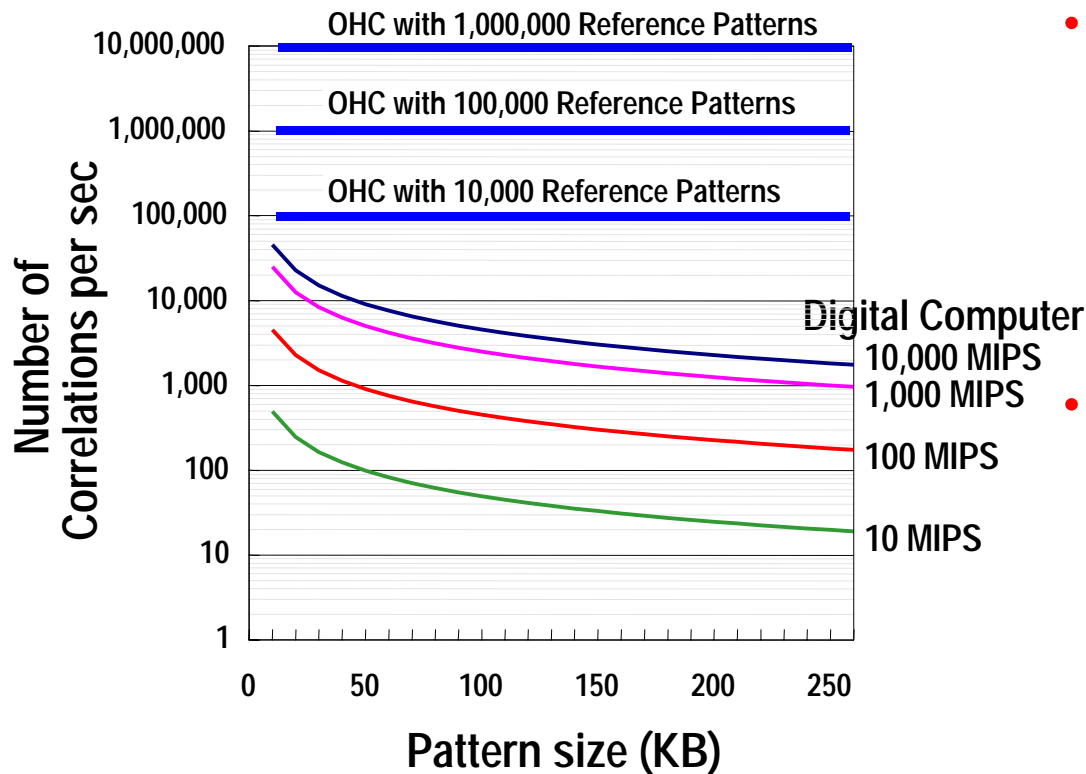
Bradley
Challenger
Humvee
Leopard
LVTP7A1
M1A1
M3
M60
Merkava
Mutt
T72
V100



Performance Advantages of OHC

Correlation Rate Comparison

Chart 7



- 10,000 Templates have already been demonstrated
- Straightforward to increase by 10X to 100X
- Practical computation speed is set by SLM size & frame rate (100-1000 fps)

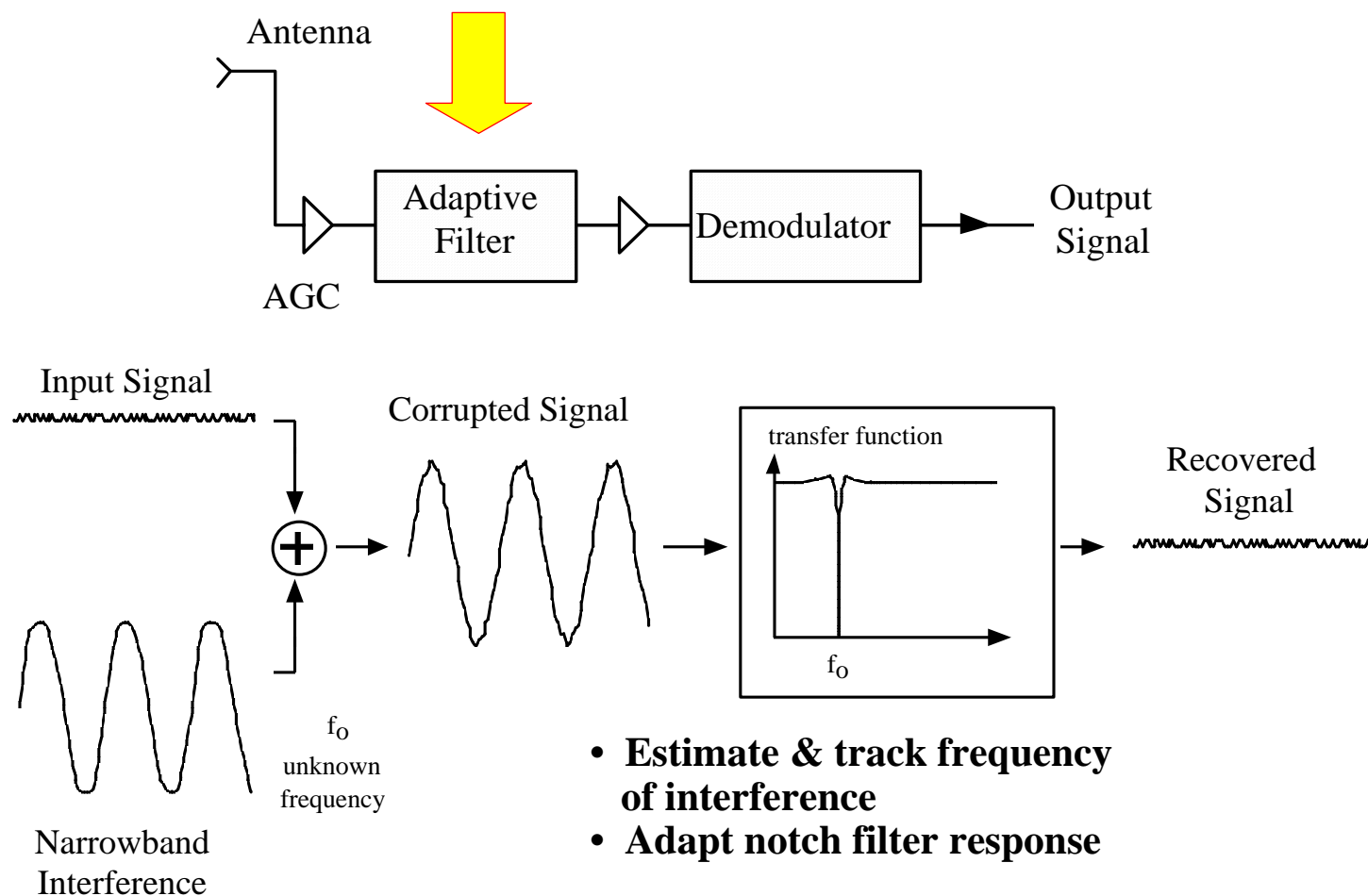
- **Electronic processors**
 - Require high performance serial memory access (500 MB/sec)
 - Require processors with ever increasing power
- **Holographic correlation**
 - Massively parallel memory access
 - Massively parallel computation

OHC offers 100X or more improvement in correlation rate



Nonlinear Adaptive Interference Cancellation

Chart 8

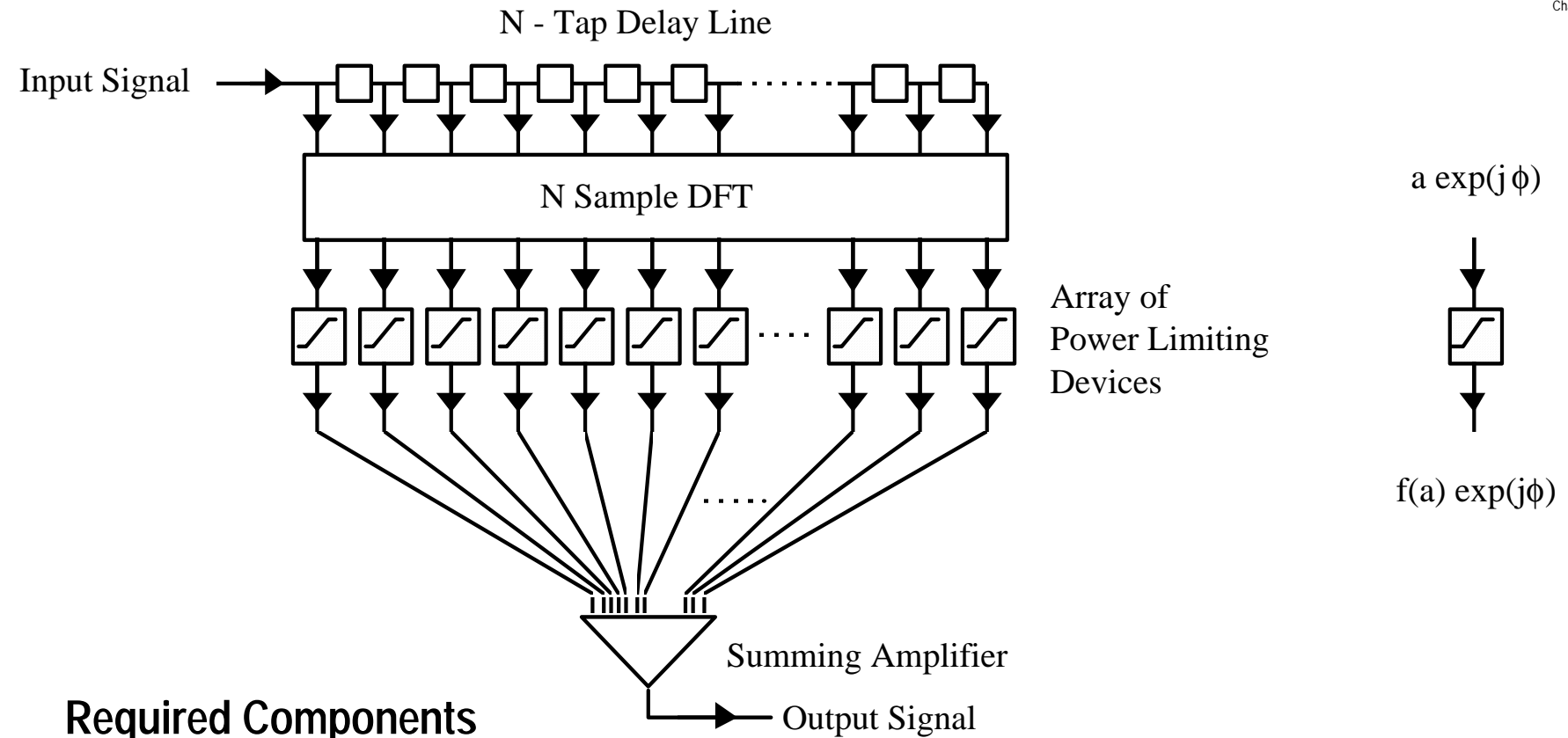


*Gov't need for nonlinear adaptive filter
which can selectively filter jamming*



Chart 9

Electronic Implementation: FIR Nonlinear Filter Architecture



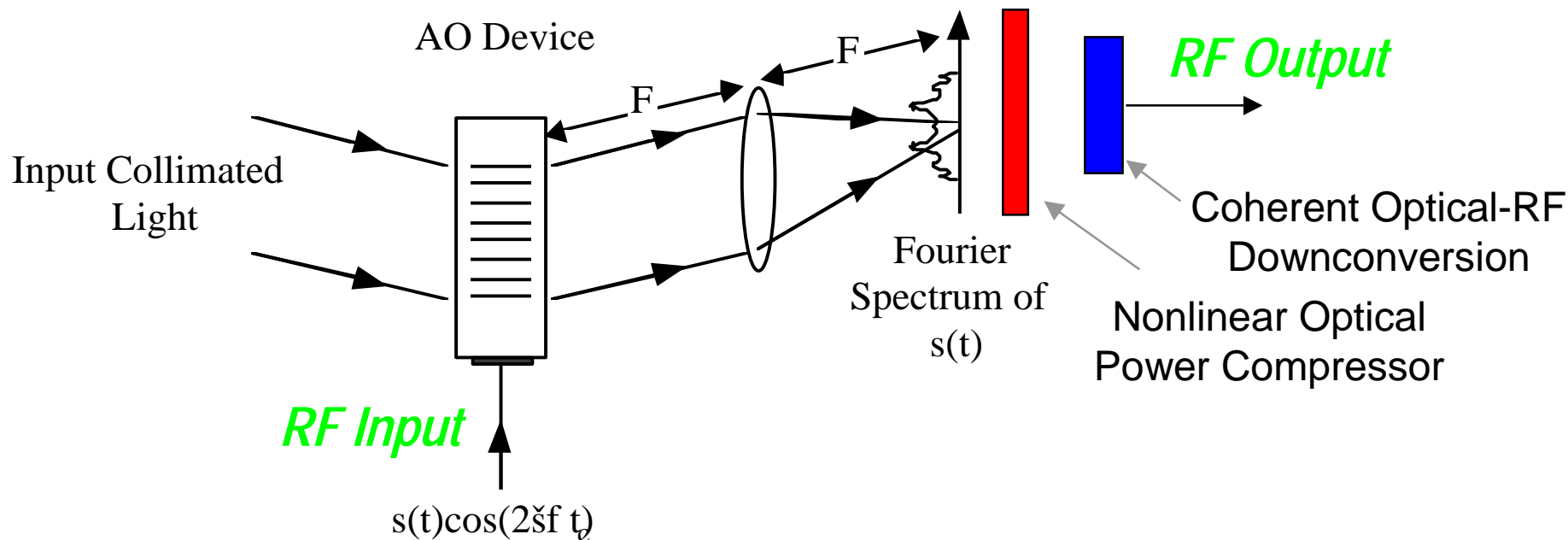
Required Components

- N Tap delays
- An N-Sample DFT
- N power limiting devices
- An N-input Summing Amplifier

Electronic approach to solve jamming is complex and requires large number of components



Chart 10



- Two analog optical processing functions enabled
 - Fourier transform
 - Nonlinear limiting
- Built-in RF-Opt-RF conversion
- Integrated optical implementation possible

Optical approach to solve jamming problem is straightforward and enables greater performance at reduced cost



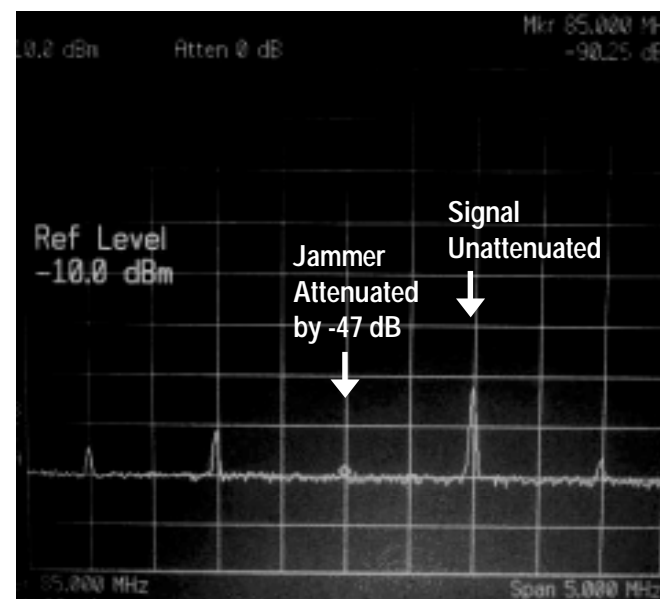
Chart 11

NAIL Experimental Results

Spectrum of the Input Signal
(Nonlinear Optical Power Compressor Off)



Spectrum of the Output Signal
(Nonlinear Optical Power Compressor On)



Theory predicts jamming attenuation of up to 120 dB is possible using NAIL

Outline

Chart 12

- Two analog optical signal processing examples
 - Optical Holographic Correlator (OHC)
 - Nonlinear Adaptive Interference Cancellation (NAIL)
- **Interesting ASOP applications**
- Concluding comments

Space-Time Adaptive Processing (STAP)

Chart 13

- STAP is highly desirable for:
 - Clutter rejection and jammer suppression in modern tactical radar
 - Interference rejection and multipath mitigation in wideband communications (e.g., CDMA)
- STAP has been shown to be superior in both Radar and Comms to separate spatial-domain (e.g., smart antenna) and time-domain (e.g., adaptive filter) processing
- To achieve real-time capability, the spatial and temporal filtering inherent to STAP require extreme computation speed: 20 – 100 Gflops

Photonic technology located between the RF antenna and the STAP processor can greatly reduce the computational burden by analog pre-processing (e.g., acousto-optical rejection of jammers by NAIL)

Adaptive Antenna Processing

Chart 14

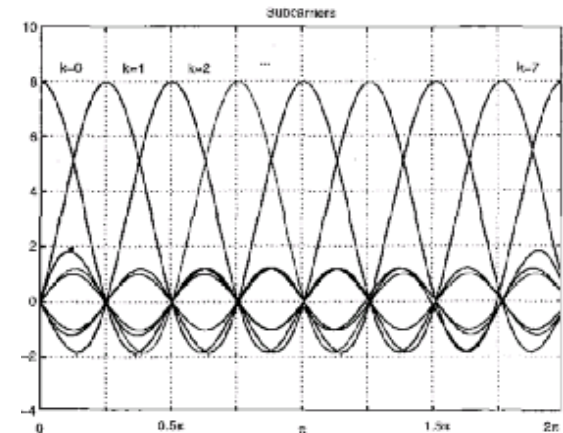
- Null steering and beam forming applications require Space-Time Adaptive signal Processing (STAP)
 - Need to solve very large set of linear equations
 - LMS and RLS algorithms currently used to avoid matrix inversion
 - LMS more common due to speed and size constraints
 - Coefficient update based on comparison of hypothesis with received data
 - RLS provides faster convergence
 - Coefficient update based on matrix operations
- Performance limited due to computational constraints
 - Unable to take full advantage of STAP due to approximations made

AOSP allows fast matrix operations (inversion) for faster convergence to take full advantage of STAP

Orthogonal Frequency Division Multiplexing (OFDM)

Chart 15

- OFDM allows multipath mitigation at high data rates due to larger symbol widths
- High data rate applications require fast and large FFTs
 - Large FFTs allow more carriers, more flexibility for high rates
 - For 1 Gbps, > 1024 point FFT required in several microseconds
 - 1024 pt. FFT processing requirements depend on implementation
 - Split radix implementation
 - > 25000 complex additions
 - > 7000 real multiplications
 - These require a minimum of 8000 MIPS



AOSP could allow very fast FFT to enable 1 Gbps wireless OFDM in a multipath environment

Code Division Multiple Access Systems

Chart 16

- Performance improvements using joint detection receivers
 - Accommodates both multi-path and multiple access interference
 - Estimate multiple access interference and separate from desired
- System performance limited by computational constraints
 - Unable to take full advantage of approach due to approximations
 - Optimal solution requires matrix inversion every several ms
 - Current digital technology limits performance improvements
 - Joint detection matrix size is $L \times N$
 - N users (typically 1000)
 - L multipath components per user (typically 4-5)

Optical signal processing allows very fast matrix inversion to optimize performance improvements using joint detection

Electronic Counter Measures

Chart 17

- Requires fast acquisition of enemy communications
- Current digital technology limitations
 - High speed
 - Large bandwidth
- Very fast spectrum analysis is required
 - 20 MHz to 3 GHz or higher frequency range
 - Hundreds of KHz resolution implies up to 16,384 pt FFT
 - Hopping systems imply ~1 ms time scale

Fast Fourier Transform (FFT) in optical domain for very fast wideband spectral analysis would be a system enabler

Conclusions

Chart 18

- AOSP offers unique advantages for “specialty” computing
 - Image processing (e.g., ATR)
 - Nonlinear filtering (e.g., NAIL)
 - Matrix inversion (e.g., Adaptive Antenna Processing, Code Division Multiple Access Systems)
 - FFT (e.g., Electronic Countermeasures, OFDM)
- ➔ • We believe that performance gains comparable to those for matrix correlation observed with the OHC are obtainable
- Integration (with electronics) is a key requirement
 - “Electronics friendly”; “Embedded optics”; “SMA on both sides”
 - Rugged
 - Compact
 - Flip-chippable (as a goal)